

UNIVERSITY OF ILLINOIS
20 FEB 1915

THE NOMENCLATURE OF THE MICROSCOPIC SUBSTANCES AND STRUCTURES OF STEEL AND CAST IRON. □ NOMENCLATURE OF SOME TECHNICAL TERMS.

RECOMMENDED BY THE SIXTH CONGRESS
OF THE INTERNATIONAL ASSOCIATION FOR
TESTING MATERIALS, HELD IN NEW YORK.
SEPTEMBER 3—7, 1912.

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PUBLISHED BY THE INTERNATIONAL ASSOCIATION
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INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS

MEMBERSHIP in 1914: 2769.

HEAD OFFICE: VIENNA (AUSTRIA) II. NORDBAHNSTRASSE 50.

The objects of the Association are: — the development and unification of standard methods of testing; the examination of the technically important properties of materials of construction and other materials of practical value, the perfecting of apparatus used for this purpose and finally the drawing up of international unified specifications.

These objects will be furthered:

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2. By the publication of an official Journal.
3. By any other means that may appear desirable.

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The President, the Vice-Presidents and the General-Secretary constitute an Executive Committee, which will be charged with taking temporary decisions between Council Meetings. Such decisions must later be submitted to the Council for final approval.

The resolutions of the Congresses on technical problems merely serve to express the opinion of the majority. They are therefore in the form of recommendations and are in no way binding.

The technical problems to be considered by the Association will be decided upon by the Congresses or by the Council, and will be duly referred to committees or referees appointed by the Council.

In the event of the Association being dissolved, any funds belonging to it will be handed over to the "International Red Cross Association".

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PREFACE.

At the Copenhagen Congress in 1909 Committee 24 nominated to draw up a uniform nomenclature for Iron and Steel, under the Chairmanship of Professor Henry M. Howe of New York, presented in addition to a list of definitions and polyglot tables for Iron and Steel in general commercial use, a proposal for definitions of its microscopic constituents. At the same Congress a proposal was also made by several investigators who had voluntarily met together for this purpose concerning the Nomenclature of such Microscopic Constituents.

In consequence of this, the Council at its XXI Meeting in Brussels, August 13, 1910, on the motion of Professor Howe, resolved to assign the Uniform Nomenclature of Microscopic Constituents of Iron and Steel to a special Committee as an independent problem, and to appoint a separate Committee (53), under the Chairmanship of Professor Henry M. Howe, which was finally composed as follows:

Chairman: Professor Henry M. Howe, New York.

Secretary: Prof. A. Sauveur, Cambridge, Mass.

Members: Prof. C. Benedicks, Stockholm, Dr. H. C. H. Carpenter, Manchester, Prof. W. Campbell, New York, Prof. L. Guillet, Paris, Prof. E. Heyn, Berlin, F. Osmond, Paris¹⁾, Dr. W. Rosenhain in Teddington, Prof. A. Stansfield, Montreal, Dr. J. E. Stead, Middlesborough, Prof. F. Wüst, Aix la Chapelle.

This Committee worked out the Nomenclature of the Microscopic Substances and Structures of Steel and Cast Iron for the VI Congress 1912, held in New York, and this Nomenclature was unanimously accepted by the Congress.

Through this acceptance the work of the Committee was finally ended and therefore at the XXV Meeting held in Amsterdam March 15,

¹⁾ M. Osmond's lamented death occurred before the Congress, but he had approved of the report in what was substantially its final form.

1913, the Council, after having past a vote of thanks to the Committee, resolved to dissolve it.

At the XXVI Meeting held in Turin April 4, 1914, the Council decided to have the nomenclature as accepted by the Congress, published in a separate form.

This decision is herewith carried out.

Before passing to this however it is deemed advisable to reprint the introduction of the report of the Committee containing the general views by which they were guided in establishing this Nomenclature.

“The conditions which we meet are (1) that we need definitions on which all can agree; this implies that they must be free from all contentious matter, and be based on what all admit to be true. (2) That the reader must needs know the current theories as to the constitution of these substances, and these theories are necessarily contentious. We meet these conditions by the plan of giving (1), the Name which we recommend for general use, followed immediately in parentheses by the other names used widely enough to justify recording them; (2) the Definition proper, based on an undisputed quality, e. g. that of austenite which we base on its being an iron-carbon solid solution, purposely omitting all reference to the precise nature of solvent and solute; and (3) Constitution etc. etc., in which we give the current theories as to the nature of solvent and solute and appropriate descriptive matter.

The distinction between these three parts should be understood. (1) The Names actually used are matter of record and indisputable. (2) The Definitions are matters of convention or treaty, binding on the contracting parties, though subject to denouncement, preferably based on some determinable property of the thing defined as distinguished from any theory as to its nature, or if necessarily based on any theory it should be a theory which is universally accepted. It is a matter purely of convention and general convenience what individual property of the thing defined shall form the basis of the definition. The name and the definition should endure permanently, except in the case of a definition based on an accepted theory, which must be changed if the theory should later be disproved. (3) Theories and Descriptions are not matters of agreement or convention but dependent on observation, and therefore always subject to be changed by new discoveries. They are temporary in their nature, as distin-

guished from the names and definitions which should be fixed, at least relatively.

This case of austenite illustrates the advantage of non-indicative names. The names which we propose to displace, "gamma iron" and "mixed crystals", imply definite theories as to the nature of austenite, and hence might have to be abandoned in case those theories were later disproved. The name "austenite" implies nothing, like mineralogical names in general, and hence is stable in itself. Our infant branch of science may well learn from its elder sister, which has tried and proved the advantage of this non-indicative naming.

In those cases in which a name has been used in more than one sense we advise the retention of one and the abandonment of the others, having obtained the consent of the proposers of such names for their abandonment.

Many whose judgment we respect object to our including certain of the less used names, e. g. from i to n in our list, holding them either to be confusing or to be needless.

It is true that several names (hardenite, martensite, sorbite, etc.), have been used with various meanings, and hence confusingly, in spite of which most of them should be retained, each with a single sharp-cut definition, because they are so useful.

As regards the alleged needlessness of certain names, it is for each writer to decide whether he does or does not need names with nice shades of meaning, such as osmondite and troosto-sorbite. Those who look only at the general outlines and not at the details have no right to forbid the workers in detail from having and using words fitting their work; nor have those whose needs are satisfied by the three primary colors a right to forbid painters, dyers, weavers, and others from naming the many shades with which they are concerned. Like the lexicographer we must serve the reader by explaining those words which he will meet, whether we individually use or condemn them. We feel that we have exhausted our powers in cautioning writers that certain words are rare and not likely to be understood by most readers, or are improper for any reason, and in urging the complete abandonment of those withdrawn by their proposers.

Needless words will die a natural death; needed ones we cannot kill. The good we might do in hastening the death of the moribund by omitting them from this report is less than the good we do by teaching

their meaning to those who will meet them in ante-mortem print. These readers have rights. We serve no class, but the whole.

Illustrations. At the end of the several descriptions the reader is referred to good illustrations in Osmond and Stead's *Microscopic Analysis of Metals*, Griffin & Co., London, 1904.

The theoretical matter in this report is given solely for exposition and the committee disclaims the intent to impose any theory. This report is offered for adoption subject to this disclaimer on the ground that the adoption of theories is beyond the powers of a Congress.

THE NOMENCLATURE OF THE MICROSCOPIC SUBSTANCES AND STRUCTURES OF STEEL AND CAST IRON*).

Recommended by the Sixth Congress of the International Association for Testing Materials, held at New York, Sept. 1912.

I. List of Microscopic Substances.

The microscopic substances here described consist of:

1. Metarals, true phases, like the minerals of nature. These are either elements, definite chemical compounds, or solid solutions and hence consisting of definite substances in varying proportions. These include austenite, ferrite, cementite, and graphite.

2. Aggregates, like the petrographic entities as distinguished from the true minerals. These mixtures may be in definite proportions, i. e. eutectic, or eutectoid mixtures, (ledeburite, pearlite, steadite) or in indefinite proportions (troostite, sorbite). Those aggregates which are important for any reason are here described.

(Many true minerals, such as mica, felspar, and hornblende, are divisible into several different species so that these true mineral names may be either generic or specific. These genera and species are definite chemical compounds, in which one element may replace another. Other minerals, such as obsidian, are solid solutions in varying proportions, and in these also one element may replace another. Metarals like minerals differ from aggregates in being severally chemically homogeneous.)

These two classes may be cross classified into:

A) The iron-carbon series, which come into being in cooling and heating.

*) The theoretical matter in this Nomenclature is given solely for exposition and the committee entrusted with the drawing up of this work disclaimed the intent to impose any theory. This Nomenclature was offered for adoption subject to this disclaimer, on the ground that the adoption of theories is beyond the powers of a Congress.

B) The important impurities, manganese sulphide, ferrous sulphide, slag, etc.

C) Other substances.

The most prominent members of the iron-carbon series are:

I. molten iron, metal, molten solution, but hardly a microscopic constituent.

II. the components which form in its solidification:

- a) austenite, solid solution of carbon or iron carbide in iron, metal;
- b) cementite, definite metal, Fe_3C ;
- c) graphite, definite metal, C.

III. the transition substances which form through the transformation of austenite during cooling:

- d) martensite, metal of variable constitution; its nature is in dispute;
- e) troostite, indefinite aggregate, uncoagulated mixture;
- f) sorbite, indefinite aggregate, chiefly uncoagulated pearlite plus ferrite or cementite;

IV. products¹⁾ of the transformation of austenite:

- g) ferrite;
- h) pearlite.

This transformation may also yield cementite and graphite as end products in addition to those under b and c.

In addition to the above, the names of which are universally recognized and in general use, the following names have been used more or less.

- i) ledeburite (Wüst), definite aggregate, the austenite-cementite eutectic;
- j) ferronite (Benedicks) hypothetical definite metal, β iron containing about 0.27 per cent of carbon;
- k) steadite, (Sauveur) definite aggregate, the iron-phosphorus eutectic (rare);

And three transition stages in the transformation of austenite, viz:

- l) hardenite, (Arnold) collective name for the austenite and martensite of eutectoid composition;
- m) osmondite, (Heyn) boundary stage between troostite and sorbite;

¹⁾ In hypo-eutectoid steels these habitually play the part of end products, though according to the belief of most, the true end of the transformation is not reached till the whole has changed into a conglomerate of ferrite plus graphite.

n) troosto-sorbite, (Kourbatoff) indefinite aggregate, the troostite and the sorbite which lie near the boundary which separates these two aggregates; (obsolescent).

II. Definitions and Descriptions.

Carbon iron equilibrium diagram, Fig. 1. Under the several substances about to be described an indication will be given of the parts of the carbon iron equilibrium diagram Fig. 1 to which they severally correspond.

Austenite, Osmond (Fr. Austénite, Ger. Austenit called also mixed crystals and gamma iron. Up to the year 1900 often called

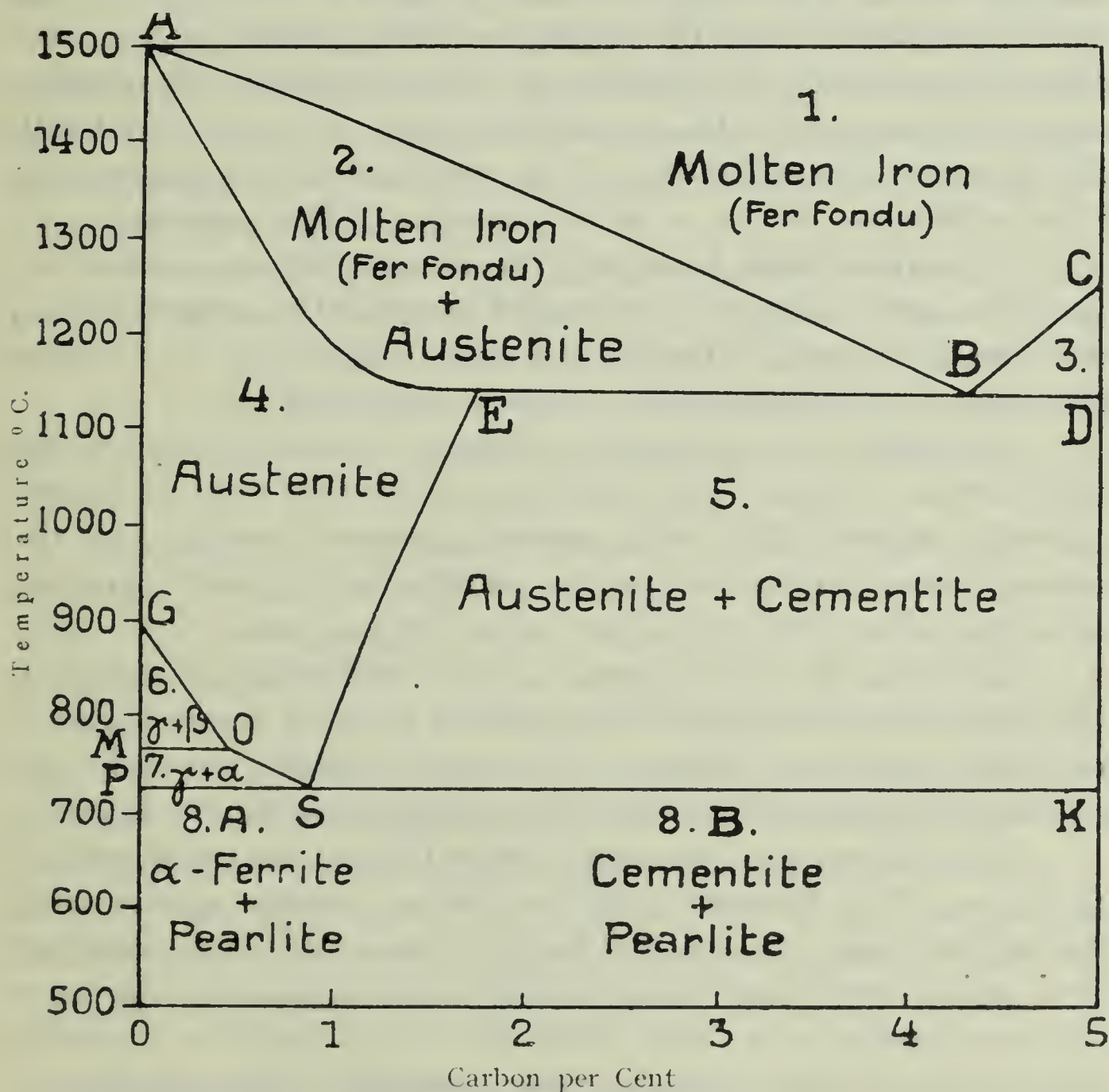


Fig. 1.

The line PSK is often called " A_1 ".

The line GOS is often called " A_3 ", and this name is sometimes applied to the line SE.

martensite, and wrongly sometimes still so called). Metaral of variable composition.

Definition. The iron-carbon solid solution as it exists above the transformation range or as preserved with but moderate transformation at lower temperatures, e. g. by rapid cooling, or by the presence of retarding elements, (Mn, Ni, etc.), as in 12% manganese steel and 25% nickel steel.

Constitution and Composition. A solid solution of carbon or iron carbide (probably Fe_3C) and gamma iron, normally stable only above the line PSK of the carbon iron diagram. It may have any carbon content up to saturation as shown by the line SE viz.: — about 0.90% at S (about 725° C) to 1.7% at E (about 1130°). The theory that the iron and the carbide or carbon, instead of being dissolved in each other, are dissolved in a third substance, the solution of eutectic composition (Fe_{24}C , called hardenite) is not in accord with the generally accepted theory of the constitution of solutions, and is not entertained widely or by any member of this committee.

Crystallization. Isometric. The idiomorphic vug crystals are octahedra much elongated by parallel growth. The etched sections show much twinning. (Osmond and most authorities.) Le Chatelier believes it to be rhombohedral. Cleavage octahedral.

Varieties and genesis. 1. Primary austenite formed in the solidification of carbon steel and hypo-eutectic cast iron; 2. eutectic austenite, interstratified with eutectic cementite, making up the eutectic formed at the end of the solidification of steel containing more than about 1.7% of carbon, and of all cast iron.

Equilibrium. It is normal and in equilibrium in Region 4, and also associated with beta iron in Region 6, with α iron in Region 7, and with cementite in Region 5. It should normally transform into pearlite with either ferrite or cementite on cooling past A_1 into Region 8.

Transformation. In cooling slowly through the transformation range. Ar_3 — Ar_1 , austenite shifts its carbon content spontaneously through generating pro-eutectoid ferrite or cementite, to the eutectoid ratio, about 0.90%, and then transforms with increase of volume at Ar_1 into pearlite, q. v., with which the ejected ferrite or cementite remains mixed. Rapid cooling and the presence of carbon, manganese, and nickel obstruct this transformation, 1. retarding it and 2. lowering the temperature at which it actually occurs, and in addition 3. manganese and nickel lower the temperature at which in equilibrium it

is due. Hence by combining these four obstructing agents in proper proportions the transformation may be arrested at any of the intermediate stages, martensite, troostite, or sorbite¹⁾, q. v., and if arrested in an earlier stage, it can be brought to any later desired stage by a regulated reheating or "tempering". For instance, though a very rapid cooling in the absence of the three obstructing elements checks the transformation but little, and only temporarily, yet if aided by the presence of a little carbon, it arrests the transformation wholly in the martensite stage; and in the presence of about 1.50% of carbon such cooling retains about half the austenite so little altered that it is "considerably" softer than the usually darker needles of the surrounding martensite of with which it contrasts sharply. Again either a) about 12% of manganese plus 1% of carbon, or b) 25% of nickel, lower and obstruct the transformation to such a degree that austenite persists in the cold apparently unaltered, even through a slow cooling. (Hadfield's manganese steel and 25% nickel steel, manganiferous and niccoliferous austenite respectively.)

Occurrence. When alone, (12% manganese and 25% nickel steel and Maurer's 2% carbon plus 2% manganese austenite) polyhedra, often coarse, much twinned, at least in the presence of martensite, and readily developing slip bands. In hardened high-carbon steel it forms a ground mass pierced by zig-zag needles and lances of martensite.

Etching. All the common reagents darken it much more than cementite, less than troostite or sorbite, and usually less, though sometimes more than martensite, which is recognized by its zig-zag shape, and needle structure. With ferrite and pearlite it is never associated.

Physical properties. Maurer's austenite of 2% manganese plus 2% carbon is but little harder than soft iron, and 25% nickel steel and Hadfield's manganese steel are but moderately hard. Yet as usually preserved in hardened high carbon steel, the hardness of austenite does not fall very far short of that of the accompanying martensite, probably because partly transformed in cooling. (Osmond's words are that it is "considerably" softer than that martensite.)

¹⁾ Though the transformation can be arrested in such a way as to leave the whole of the steel in the condition of martensite, it is doubted by some whether it can be so arrested as to leave the whole of it in any of the other transition stages. Troostite and sorbite caused by such arrest are habitually mixed, troostite with martensite or sorbite or both, and sorbite with pearlite or troostite or both.

Specific Magnetism very slight unless perhaps in intense fields. In Hadfield's manganese steel and 25% nickel steel; very ductile.

Illustrations. Microscopic Analysis of Metals, Figs. 20, 50, and 51, on pp. 39, 100, and 101.

Cementite (Sorby "intensely hard compound", Ger. Cementit, Fr. Cémentite, Arnold, crystallized normal carbide). Definite metaral.

Definition. Tri-ferrous carbide, Fe_3C . The name is extended by some writers so as to include tri-carbides in which part of the iron is replaced by manganese, or other elements. Such carbides may be called "manganiferous cementite", etc.

2. Occurrence. a) pearlitic. as a component of pearlite, q. v.; b) eutectic; c) primary or pro-eutectic; d) pro-eutectoid; e) that liberated by the splitting up of the eutectic or of pearlite; and f) uncoagulated in sorbite, troostite, and perhaps martensite. c), d), and e) are grouped together as "free" or "massive".

Primary cementite is generated in cooling through Region 3; eutectic cementite on cooling past the line EBD; pro-eutectoid cementite in cooling through Region 5; pearlitic cementite on cooling past the line PSK, or A_1 . Though the several varieties of cementite are generally held to be all metastable, tending to break up into graphite plus either austenite above A_1 or ferrite below A_1 , yet they have a considerable and often great degree of persistence. The graphitizing tendency is completely checked in the cold, but increases with the temperature, and with the proportion of carbon and of silicon present, and is opposed by the presence of manganese.

3. Crystallization. Orthorhombic, in plates.

1. Structure. a) Pearlitic, in parallel unintersecting plates alternating with plates of ferrite; b) Eutectic, plates forming a network filled with a fine conglomerate of pearlite with or without pro-eutectoid cementite; c) Primary, in manganiferous white cast iron etc., in rhombohedral plates; d) In hyper-eutectoid steel, pro-eutectoid cementite forms primarily a network enclosing meshes of pearlite, through which cementite plates or spines sometimes shoot if the network is coarse; e) Cementite liberated from pearlite merges with any neighbouring cementite; f) The structure of uncoagulated cementite cannot be made out. On long heating the pro-eutectoid and pearlitic cementite spheroidize slowly, and neighbouring particles merge; g) In white irons rich in phosphorus in flat plates embedded in iron-carbon-phosphorus eutectic.

5. Etching etc. After polishing stands in relief. Brilliant white after etching with dilute hydrochloric or picric acid; darkened by boiling with solution of sodium picrate in excess of sodium hydrate.

6. Physical properties. Hardest component of steel. Hardness = 6 of Mohs scale. Scratches glass and felspar but not quartz; very brittle. Specific magnetism about two-thirds that of pure iron.

Illustrations, Microscopic Analysis of Metals, Figs. 42, and 43 on pp. 84, 85.

Martensite (Fr. Martensite, Ger. Martensit), Metaral. Its nature is in dispute.

Definition. The early stage in the transformation of austenite characterized by needle structure and great hardness, as in hardened high-carbon steel.

Constitution. 1. (Osmond and others), a solid solution like austenite, q. v., except that the iron is partly beta, whence its hardness, and partly alpha, whence its magnetism in mild fields. II. (Le Chatelier) the same except that its iron is essentially alpha, and the hardness due to the state of solid solution. III. (Arnold) a special structural condition of his "hardenite" (austenite); not widely held. IV. A solid solution in gamma iron. V. (Benedicks.) The same as I, except that the iron is wholly beta, and that beta iron consists of alpha iron containing a definite quantity of gamma iron in solution.

Equilibrium. It is not in equilibrium in any part of the diagram, but represents a metastable condition in which the metal is caught during rapid cooling, in transit between the austenite condition stable above the line A_1 , and the condition of ferrite plus cementite into which the steel habitually passes on cooling slowly past the line A_1 .

Occurrence. The chief constituent of hardened carbon tool steels, and of medium nickel- and manganese-steels. In still less fully transformed steels (1.50% carbon steel rapidly quenched, etc.) it is associated with austenite; in more fully transformed ones (lower carbon steels hardened, high carbon steels oil hardened, or water hardened and slightly tempered, or hardened thick pieces even of high carbon steel) it is associated with troostite, and with some pro-eutectoid ferrite or cementite, q. v., in hypo- and hyper-eutectoid steels respectively. In tempering it first changes into troostite; at 350–400° it passes through the stage of osmondite; at higher temperatures it changes into sorbite; and at 700° into granular pearlite. On heating into the

transformation range this changes into austenite, which on cooling again yields lamellar pearlite.

Characteristic specimens are had by quenching bars 1 cm square of eutectoid steel, i. e. steel containing about 0.9% of carbon in cold water from 800° C (1472° F).

Structure. When alone, habitually in flat plates made up of intersecting needles parallel to the sides of a triangle. When mixed with austenite, zig-zag needles, lances, and shafts.

If produced by quenching after heating to 735° C, it consists of minute crystallites resembling the globulites of Vogelsang, which are rarely arranged in triangular order. At times so fine as to suggest being amorphous.

Etching. With picric acid, iodine, or very dilute nitric acid etches usually darker than austenite, but sometimes lighter, always darker than ferrite and cementite, but always lighter than troostite.

Illustrations, Microscopic Analysis of Metals, Figs. 19, p. 38, Fig. 52 on p. 102.

Ferrite (Fr. Ferrite, Ger. Ferrit), definite metal.

1. Definition. Free alpha-iron.

2. Composition. Nearly pure iron. It may contain a little phosphorus and silicon, but its carbon content if any is always small, at the most not more than 0.05%, and perhaps never as much as 0.02%.

3. Occurrence. (a), pearlitic as a component of pearlite, q. v.; (b), pro-eutectoid ferrite generated in slow cooling through the transformation range; (c) that segregated from pearlite, i. e. set free by the splitting up of pearlite, especially in low carbon steel; (d) uncoagulated as in sorbite, and probably troostite, (b) and (c) are classed together as free or massive.

Thus ferrite is normal and stable in regions 7 and 8.

4. Crystallisation, isometric, in cubes or octahedra.

5. Structure. (a) pearlitic ferrite, unintersecting parallel plates alternating with plates of cementite; (b) pro-eutectoid ferrite in low-carbon steel forms irregular polygons, each with uniform internal orientation. In higher carbon steel, after moderately slow cooling, especially in the presence of manganese, it forms a network enclosing meshes of pearlite. In slower cooling this network is replaced by irregular grains separated by pearlite; (c) the ferrite set free by the splitting

up of pearlite merges with the pro-eutectoid ferrite if any; (d) the structure of the ferrite in sorbite etc. cannot be made out.

6. Etching. Dilute alcoholic nitric or picric acid on light etching leaves the ferrite grains white with junctions which look dark. Deeper etching, by Heyn's reagent or its equivalent, reveals the different orientation of the crystals or grains, (a) as square figures parallel to the direction of the etched surface, (b) as plates which dip at varying angles and become dark or bright when the specimen is rotated under oblique illumination. Still deeper etching reveals the component cubes, (etching figures, Ätzfiguren), at least if the surface is nearly parallel to the cube faces.

7. Physical Properties. Soft; relatively weak (tenacity about 40,000 lbs. per sq. in.); very ductile; strongly ferro-magnetic; coercitive force very small.

Grain Size. For important purposes (1) etch deeply enough, e. g. with copper-ammonium chloride, to reveal clearly the junctions of the grains; (2) count on a photograph of small magnification the number of grains in a measured field so drawn as to exclude fragments of grains; after (3) determining the true grain boundaries by examination under high powers (Heyn's method). Deep nitric acid etching is inaccurate, because an apparent grain boundary may contain several grains.

Illustrations, Microscopic Analysis of Metals, Figs. 41, 56, pp. 79, 116.

Omondite (Fr. Osmondite, Ger. Osmondit).

Definition. That stage in the transformation of austenite at which the solubility in dilute sulphuric acid reaches its maximum rapidity. Arbitrarily taken as the boundary between troostite and sorbite.

Earlier Definition. Defined at the Vth Congress as having the "maximum solubility in acids and by a maximum coloration under the action of acid metallographic reagents". The present definition is confined to maximum rapidity of dissolving, because we do not yet know that this in all cases co-exists with the maximum depth of coloration, and in any case in which these two should not co-exist, the old definition does not decide which is true osmondite.

Constitution. The following hypotheses have been suggested, none of which has firm experimental foundation. 1. A solid solution

of carbon or an iron carbide in alpha iron. 2. The colloidal system of Benedicks in its purity, troostite being this system while forming at the expense of martensite, and sorbite, being this system coagulating and passing into pearlite. 3. The stage of maximum purity of amorphous alpha iron on the way to crystallising into ferrite.

Occurrence. Hardened carbon steel of about 1% of carbon when reheated (tempered) to 350—400° C passes through the stage of troostite to that of osmondite, and on higher heating to that of sorbite. What variation if any from this temperature is needed to bring hardened steel of other carbon content to the osmondite stage is not known. In that it represents a true boundary state between troostite and sorbite, it differs in meaning from troosto-sorbite, which embraces both the troostite and the sorbite which lie near this boundary. Indeed osmondite has sometimes been used in this looser sense. Writers are cautioned that, however useful these terms may prove for making these nice discriminations, they are not likely to be familiar to general readers.

Etching. According to Heyn it differs from troostite and sorbite in being that stage in tempering which colors darkest on etching with alcoholic hydrochloric acid.

The present definition and description of osmondite should displace previous ones, because they have the express approval of Professor Heyn, the proposer of the name, and M. Osmond himself.

Ferronite (Fr. Ferronite, Ger. Ferronit) (Benedicks) hypothetical definite metaral.

Definition. Solid solution of about 0.27% of carbon in beta iron.

Occurrence, (hypothetical). In slowly cooled steels and cast iron containing 0.50% of combined carbon or more, that which is generally believed to be ferrite, whether pearlitic or free, is supposed by Benedicks to be ferronite.

Hardenite (Fr. Hardenite, Ger. Hardenit).

Definition. Collective name for austenite and martensite of eutectoid composition. It includes such steel (1) when above the transformation range, and (2) when hardened by rapid cooling.

Observations. On the generally accepted theory that austenite is a solid solution of carbon or an iron carbide in iron, hardenite is

the solution of the lowest transformation temperature, i. e. the eutectoid. The theory that instead it is a definite chemical compound, Fe_{24}C , is considered under Austenite. Its proposer includes under hardenite both eutectoid (0.90% carbon) austenite when above the transformation range, and the martensite into which that austenite shifts in rapid cooling (hardening).

Other Meanings. Originally (Howe, 1888) collective name for austenite and martensite of any composition in carbon steel. Osmond (1897), austenite saturated with carbon, Both these meanings are withdrawn by their proposers.

Pearlite (Sorby's "pearly constituent". At first written "pearlyte" Fr. Perlite, Ger. Perlit) Aggregate.

Definition. The iron-carbon eutectoid, consisting of alternate masses of ferrite and cementite.

Constitution and Composition. A conglomerate of about 6 parts of ferrite to 1 of cementite. When pure, contains about 0.90% of carbon, 99.10% of iron.

Occurrence. Results from the completion of the transformation of austenite brought spontaneously to the eutectoid carbon-content, and hence occurs in all carbon steels and cast iron containing combined carbon and cooled slowly through the transformation range, or held at temperatures in or but slightly below that range, long enough to enable the ferrite and cementite to coagulate into a mass microscopically resolvable. Hence it is the normal constituent in Region 8. Its ferrite is stable but its cementite is metastable and tends to transform into ferrite and graphite.

Varieties and Structure. Because pearlite is formed by the coagulation of the ferrite and cementite initially formed as the irresolvable emulsion, sorbite, (Arnold's sorbitic pearlite) there are the indefinitely bounded stages of sorbitic pearlite, (Arnold's normal pearlite), i. e. barely resolvable pearlite, in the border land between sorbite and laminated pearlite; granular pearlite, in which the cementite forms fine globules in a matrix of ferrite; and laminated or lamellar pearlite, consisting of fine, clearly defined, non-intersecting, parallel lamellae alternately of ferrite and cementite. The name granular pearlite was first used by Sauveur to represent what is now called sorbite. This meaning has been withdrawn.

An objection to Arnold's name "normal pearlite" is that it is likely to mislead. "Normal" here apparently refers to arising under normal conditions of cooling, but (1) it rather suggests structure normal for pearlite, which surely is the lamination characteristic of eutectics in general, and (2) the general reader has no clue as to what conditions of cooling are here called normal. Many readers are not manufacturers, and even in manufacture itself air cooling is normal for one branch and extremely slow furnace cooling for another. Arnold calls troostite "troostitic pearlite" and sorbite "sorbitic pearlite". This is contrary to general usage, which restricts pearlite to microscopically resolvable masses.

Etching. After etching with dilute alcoholic nitric or picric acid it is darker than ferrite or cementite but lighter than sorbite and troostite. A magnification of at least 250 diameters is usually needed for resolving it into its lamellae, though the pearlite of blister steel can often be resolved with a magnification of 25 diameters. The more rapidly pearlite is formed, the higher the magnification needed for resolving it.

Illustrations, lamellar pearlite. Osmond and Stead, *Microscopic Analysis*, Fig. 11, p. 19, Granular pearlite, idem Fig. 18, p. 36; Heyn and Bauer, *Stahl und Eisen* 1906, Fig. 14, opposite p. 785.

Graphite (Ger. Graphit, Fr. Graphite), definite metal.

Definition. The free elemental carbon which occurs in iron and steel.

Composition. Probably pure carbon, identical with native graphite.

Genesis. Derived in large part, and according to Goerens wholly, from the decomposition of solid cementite. Others hold that its formation as kish may be from solution in the molten metal, and that part of the formation of temper graphite may be from elemental carbon dissolved in austenite. It is the stable form of carbon in all parts of the diagram.

Occurrence. 1. as kish, flakes which rise to the surface of molten cast iron and usually escape thence;

2. as thin plates, usually curved, e. g. in gray cast-iron, representing carbon which has separated during great mobility, i. e. near the melting range;

3. as temper graphite (Ger. Temperkohle, Ledebur) pulverulent carbon which separates from cementite and austenite, especially in the annealing process for making malleablized castings.

Graphite and ferrite are sometimes associated in a way which suggests strongly that they represent a graphite-austenite eutectic. But the existence of such a true eutectic is doubted by most writers.

Properties. Hexagonal. H. 1—2. Gr. 2·255. Streak black and shining, lustre metallic; macroscopic color, iron black to dark steel gray, but always black when seen in polished sections of iron or steel under the microscope; opaque; sectile; soils paper; flexible; feel, greasy.

Troostite (Fr. Troostite, Ger. Troostit). Probably aggregate. (Arnold, troostitic pearlite).

Definition. In the transformation of austenite, the stage following m \ddot{a} rtensite and preceding sorbite (and osmondite if this stage is recognized).

Constitution and composition. An uncoagulated conglomerate of the transition stages. The degree of completeness of the transformation represented by it is not definitely known and probably varies widely. Osmond and most others believe that the transformation, while generally far advanced, yet falls materially short of completion; but Benedicks and Arnold (9) believe that it is complete. The former belief that it is a definite phase, e. g. a solid solution of carbon or an iron carbide in either g or b iron, is abandoned. Its carbon-content like that of austenite and martensite varies widely.

Occurrence. It arises either on reheating hardened (e. g. martensitic steel) to slightly below 400°, or on cooling through the transformation range at an intermediate rate, e. g. in small pieces of steel when quenched in oil, or quenched in water from the middle of the transformation range, or in the middle of larger pieces quenched in water from above the transformation range. With slightly farther reheating it changes into sorbite; with higher heating into sorbitic pearlite, then slowly into granular pearlite, and probably indirectly into lamellar pearlite. It occurs in irregular, fine-granular or almost amorphous areas, colored darker by the common etching reagents than the martensite or sorbite accompanying it. A further common means of distinguishing it from sorbite is that it is habitually associated with martensite, whereas sorbite is habitually associated with pearlite.

Areas near the boundary between troostite and sorbite are sometimes called troosto-sorbite.

Properties. Hardness, intermediate between that of the martensitic and the pearlitic state corresponding to the carbon content of the specimen. In general the hardness increases, the elastic limit rises, and the ductility decreases, as the carbon-content increases. Its ductility is increased rapidly and its hardness and elastic limit lowered rapidly by further tempering, which affects it much more markedly than sorbite.

Sorbite (Fr. Sorbite, Ger. Sorbit). Aggregate. (Arnold, sorbitic pearlite.)

Definition. In the transformation of austenite, the stage following troostite and osmondite, if this stage is recognized, and preceding pearlite.

Constitution and Composition. Most writers believe that it is essentially an uncoagulated conglomerate of irresoluble pearlite with ferrite in hypo- and cementite in hyper-eutectoid steels respectively, but that it often contains some incompletely transformed matter.

Occurrence. The transformation can be brought to the sorbitic stage (1) by reheating hardened steel to a little above 400° , but not to 700° at which temperature it coagulates into granular pearlite; (2) by quenching small pieces of steel in oil or molten lead or even by air-cooling them; (3) by quenching in water from just above the bottom of the transformation range, A_{r1} . Sorbite is ill-defined, almost amorphous, and is colored lighter than troostite but darker than pearlite by the usual etching reagents. It differs further from troostite in being softer for given carbon content, and usually in being associated with pearlite instead of martensite, and from pearlite in being irresoluble into separate particles of ferrite and cementite.

As sorbite is essentially a mode of aggregation it cannot properly be represented on the equilibrium diagram. Its components at all times tend to coagulate into pearlite, yet it remains in its uncoagulated state at all temperatures below 400° .

Properties. Though slightly less ductile than pearlitic steel for given carbon content, its tenacity and elastic limit are so high that a higher combination of these three properties can be had in sorbitic than in pearlitic steels by selecting a carbon content slightly lower than would be used for a pearlitic steel. Hence the use of sorbitic steels,

e. g. first hardened and then annealed cautiously, for structural purposes needing the best quality.

Manganese Sulphide (Fr. {Sulphure 'de Manganèse, Ger. Schwefelmangan), MnS , (Arnold and Waterhouse). Metaral.

Occurrence etc. Sulphur combines with the manganese present in preference to the iron, forming pale dove or slate gray masses, rounded in castings, elongated in forgings.

Ferrous Sulphide (Fr. Sulphure de Fer, Ger. Schwefeleisen), FeS . Metaral.

Occurrence. The sulphur not taken up by the manganese forms ferrous sulphide, FeS , which, probably associated in part with iron as an $\text{Fe}-\text{FeS}$ eutectic, forms by preference more or less continuous membranes surrounding the grains of pearlite. Color, yellow, or pale brown.

Sulphur Prints. When silk impregnated with mercuric chloride and hydrochloric acid (Heyn's and Bauer's method) or bromide paper moistened with sulphuric acid (Baumann's method) is pressed on polished steel, the position of the sulphur-bearing areas, whether of FeS or MnS , records itself by the local blackening which the evolved H_2S causes. Phosphorus bearing areas also blacken Baumann's bromide paper.

Miscellaneous.

Eutectoid, Saturated, etc. The iron carbon eutectoid is pearlite. Steel with more carbon than pearlite is called hyper-eutectoid, that with less is called hypo-eutectoid. Arnold's names "saturated", "unsaturated", and "supersaturated", for eutectoid, hypo-eutectoid, and hyper-eutectoid steel respectively, have considerable industrial use in English speaking countries, but are avoided by most scientific writers on the ground that they are misleading, because, e. g. there is only one specific temperature, A_1 , at which eutectoid steel is actually saturated, and, if any other temperature is in mind, that steel is not saturated. Above A_1 it is clearly undersaturated.

The objection to the names sorbite, troostite, martensite, and austenite, that each of them covers steel of a wide range of carbon content, is to be dismissed because a like objection applies with equal force to every generic name in existence.

NOMENCLATURE OF SOME TECHNICAL TERMS ¹⁾.

The Council, at its XX Meeting held at Frankfort-on-Maine, Febr. 5, 1910, acting on the suggestion made by Prof. A. Mesnager at the VI Congress in Copenhagen 1909, nominated a Committee for the establishing of a nomenclature of Technical Expressions which apply especially to internal stresses. There are indeed a large number of terms of badly defined signification which are constantly being used by technical men in very diverse and often in a diametrically opposite sense.

The Committee was composed as follows:

Chairman: Prof. A. Mesnager, Paris.

Members: Mr. N. Antochine, St. Petersburg, Prof. G. H. Gulliver, Edinburgh, Prof. E. Heyn, Berlin-Lichterfelde, Prof. B. Kirsch, Vienna, Prof. A. Rejtő, Budapest.

In order to make a beginning the Committee submitted the following Nomenclature to the VI Congress held in New York 1912, which was unanimously accepted.

After the Congress Prof. A. N. Talbot, Urbana Ill. joined the Committee.

The Committee is continuing its work and intends in due course to bring forward additions to this first communication.

¹⁾ An error has slipped into the Proceedings of the VI Congress. In the Nomenclature of Some Technical Terms some English expressions are not in conformity with those proposed in Report XXVIII₁ submitted by the Committee and accepted by Section C and the Full Meeting. It is therefore necessary to rectify in the Proceedings of the Closing Meeting p. 5 and in the Proceedings of the XXIV Meeting of the Council p. 439, the English terms in conformity with the above Nomenclature.

1. The VI Congress recommended for the total or absolute force the terms:

in French: Force, effort (de traction, de compression, de cisaillement);

in German: Kraft, Zugkraft, Druckkraft, Schubkraft oder Scherkraft;

in English: Force, Load (tensile, compressive, shearing), Pull and Thrust.

2. The VI Congress recommended for the forces (efforts) per unit of area:

in French: Tension, pression, cisaillement; (tension normale, pression normale, tension tangentielle);

in German: Zugspannung, Druckspannung, Schubspannung;

in English: Tension, Pressure, Shear; or Stress (tensile, compressive, shearing).

The terms: frottement intérieur, innere Reibung, internal friction, to be reserved for the resistance to gliding offered by the material in a direction parallel to the plane in which gliding occurs.

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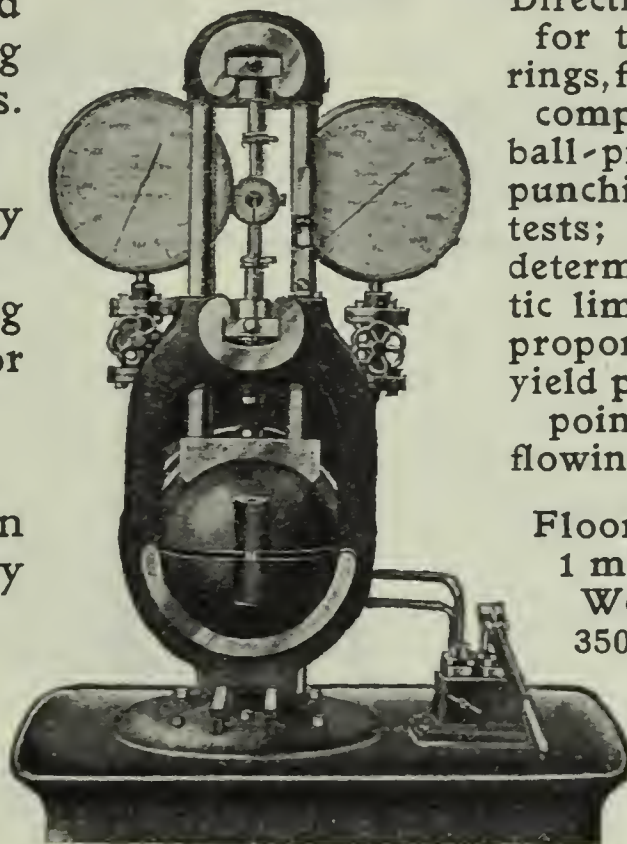
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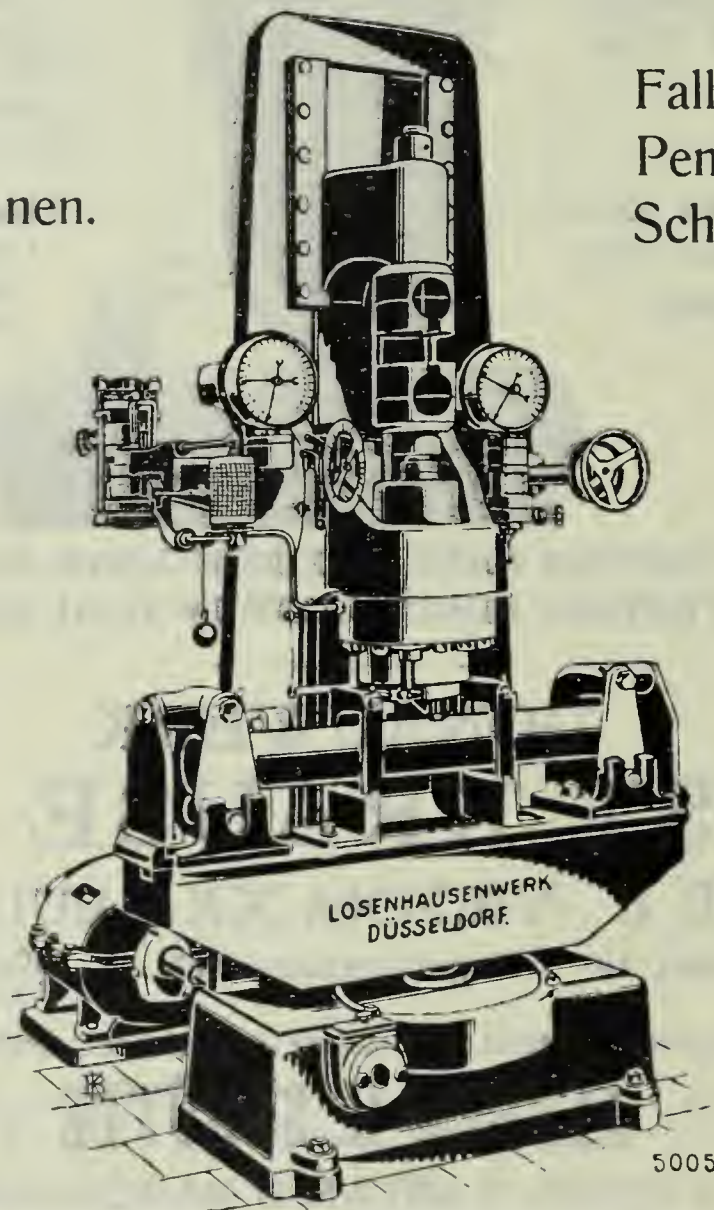
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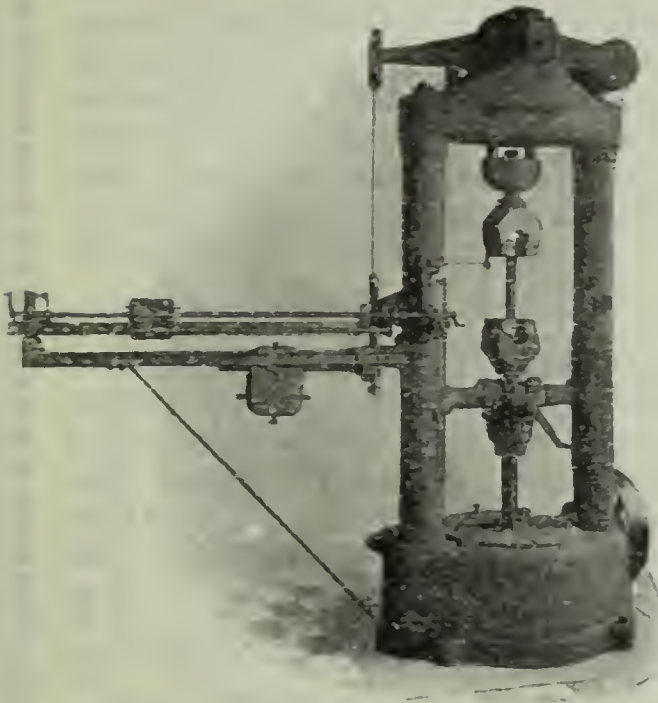


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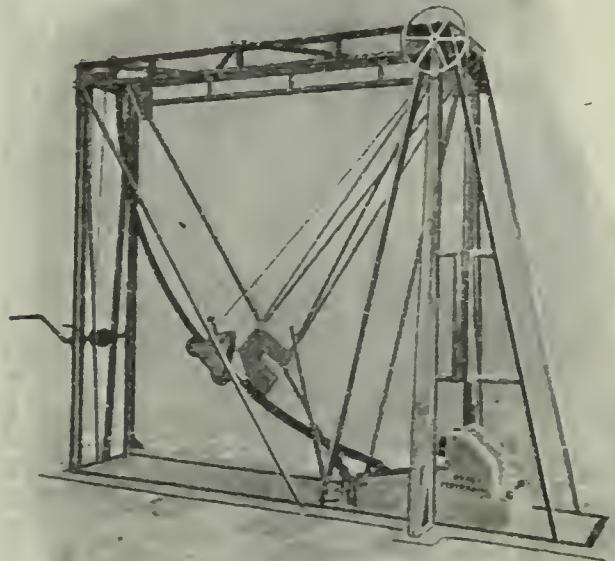
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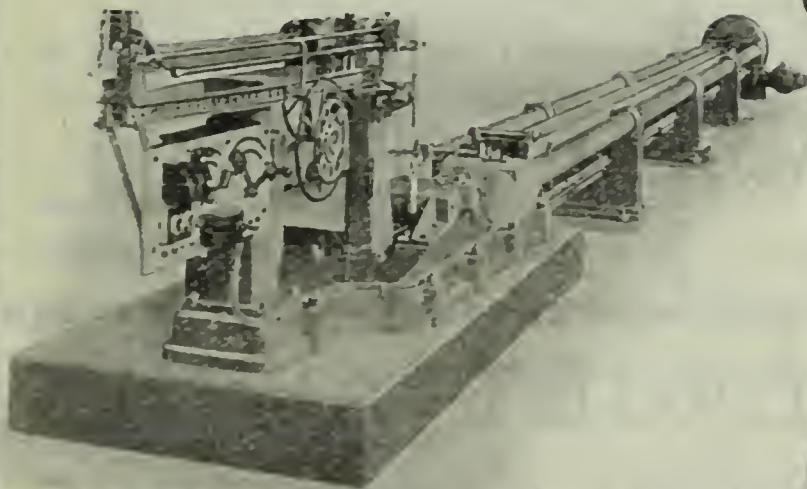
Spezial-Fabrik für
Materialprüfungs-Maschinen.



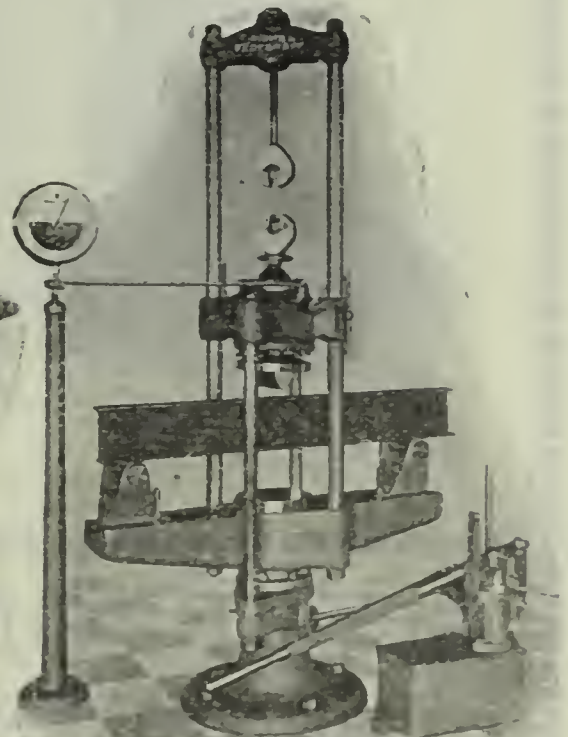
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Pendel-Schlagwerk, „System
Charpy“.

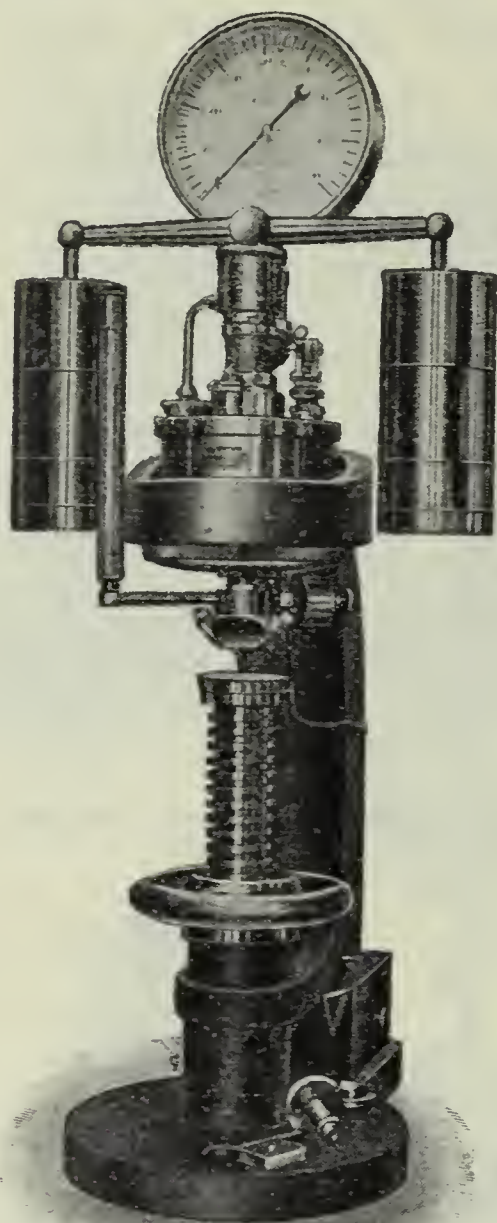


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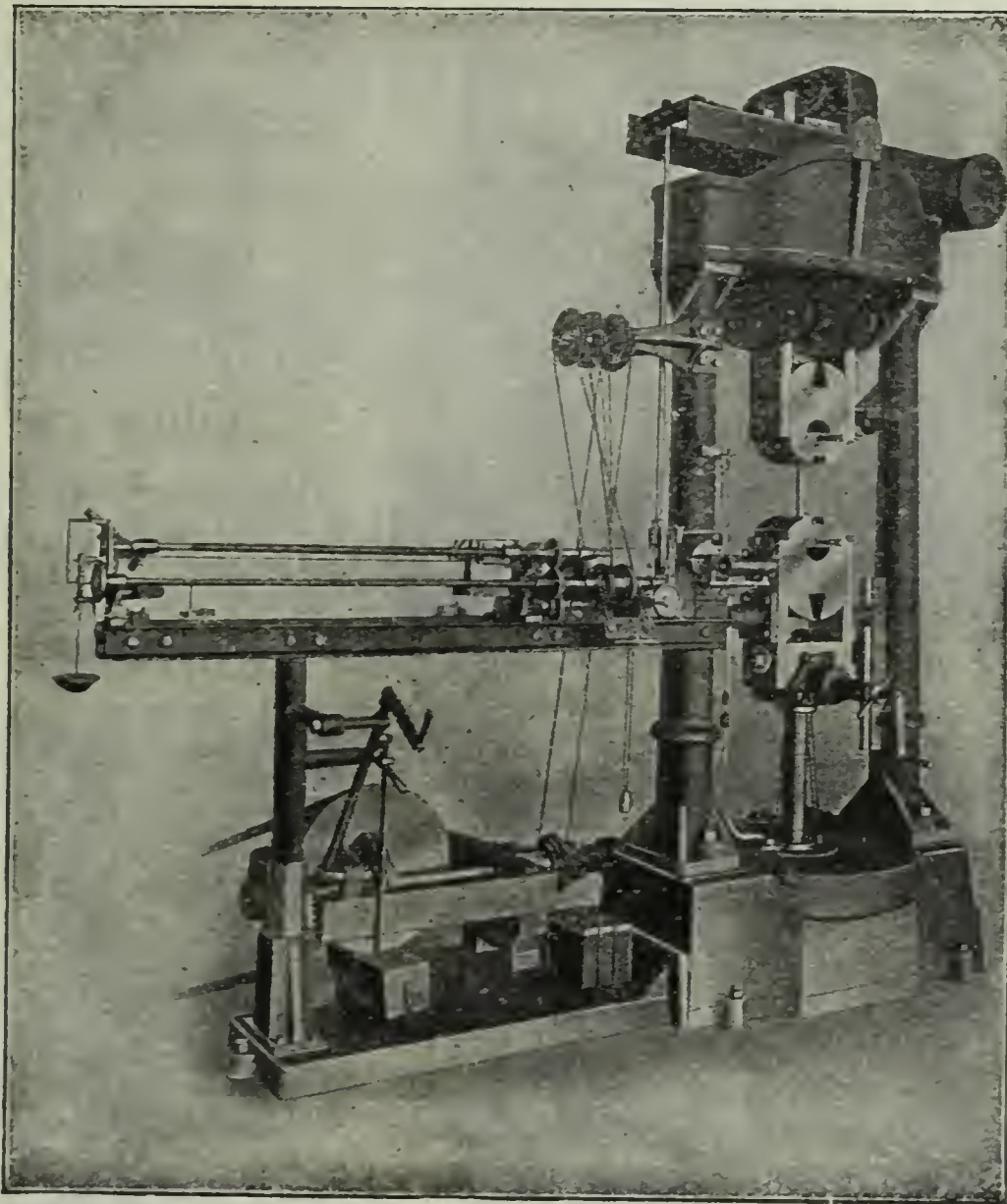
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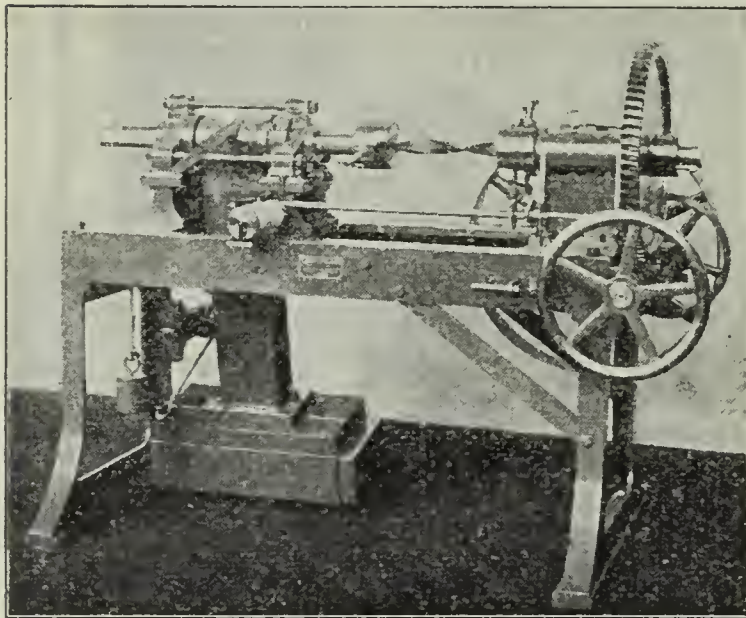
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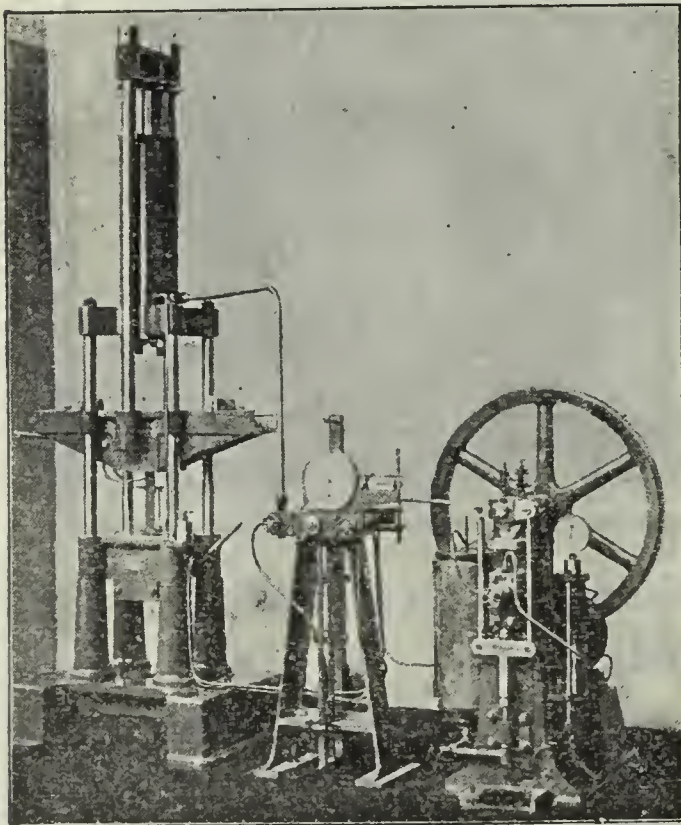
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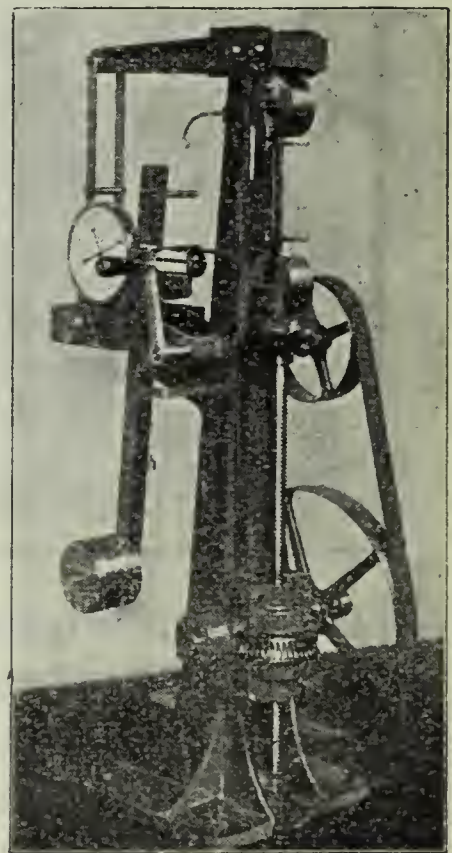
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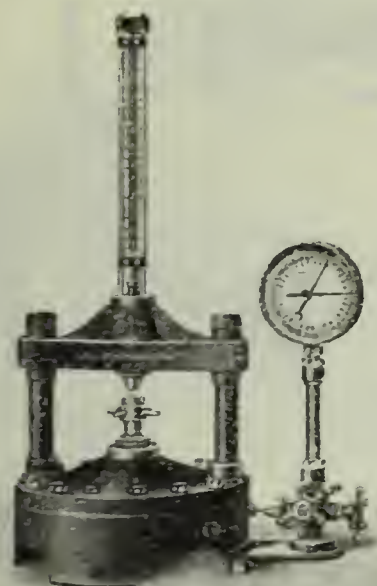


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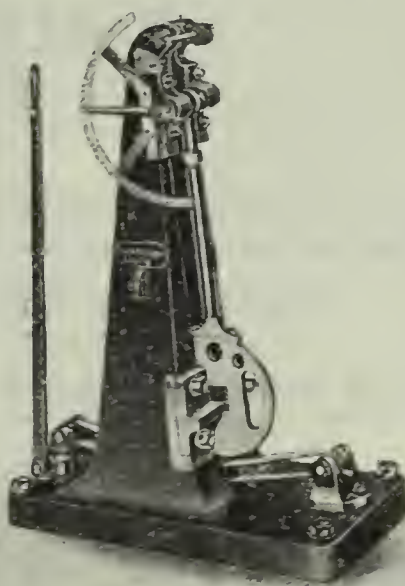


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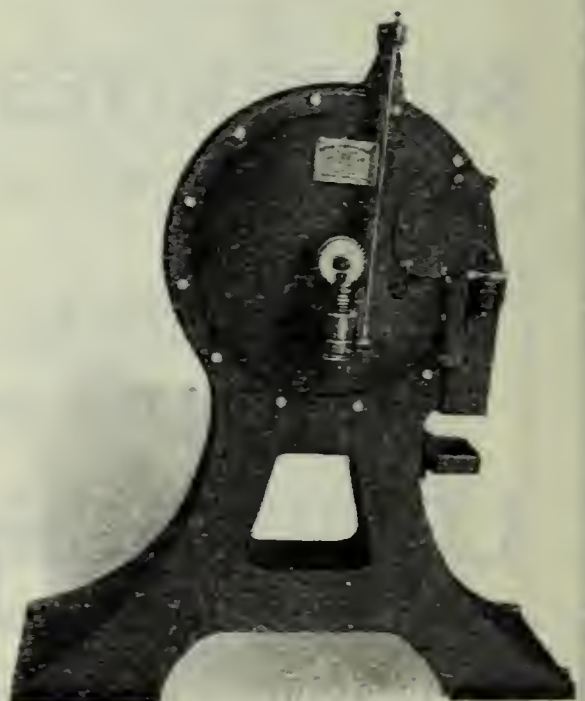
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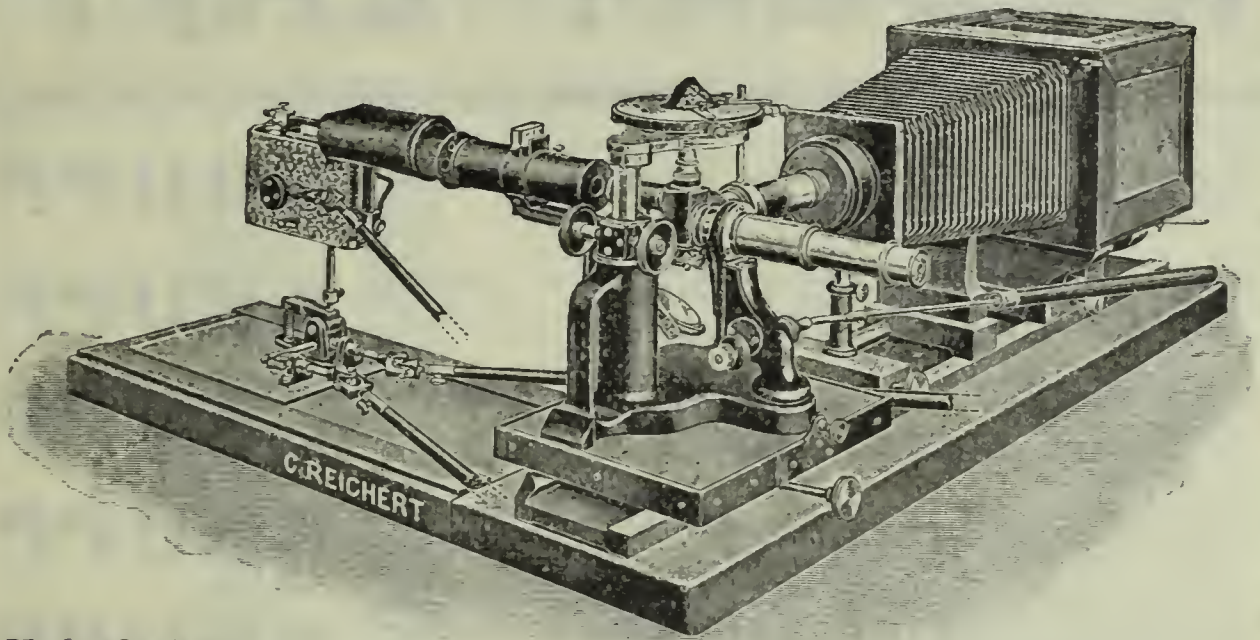


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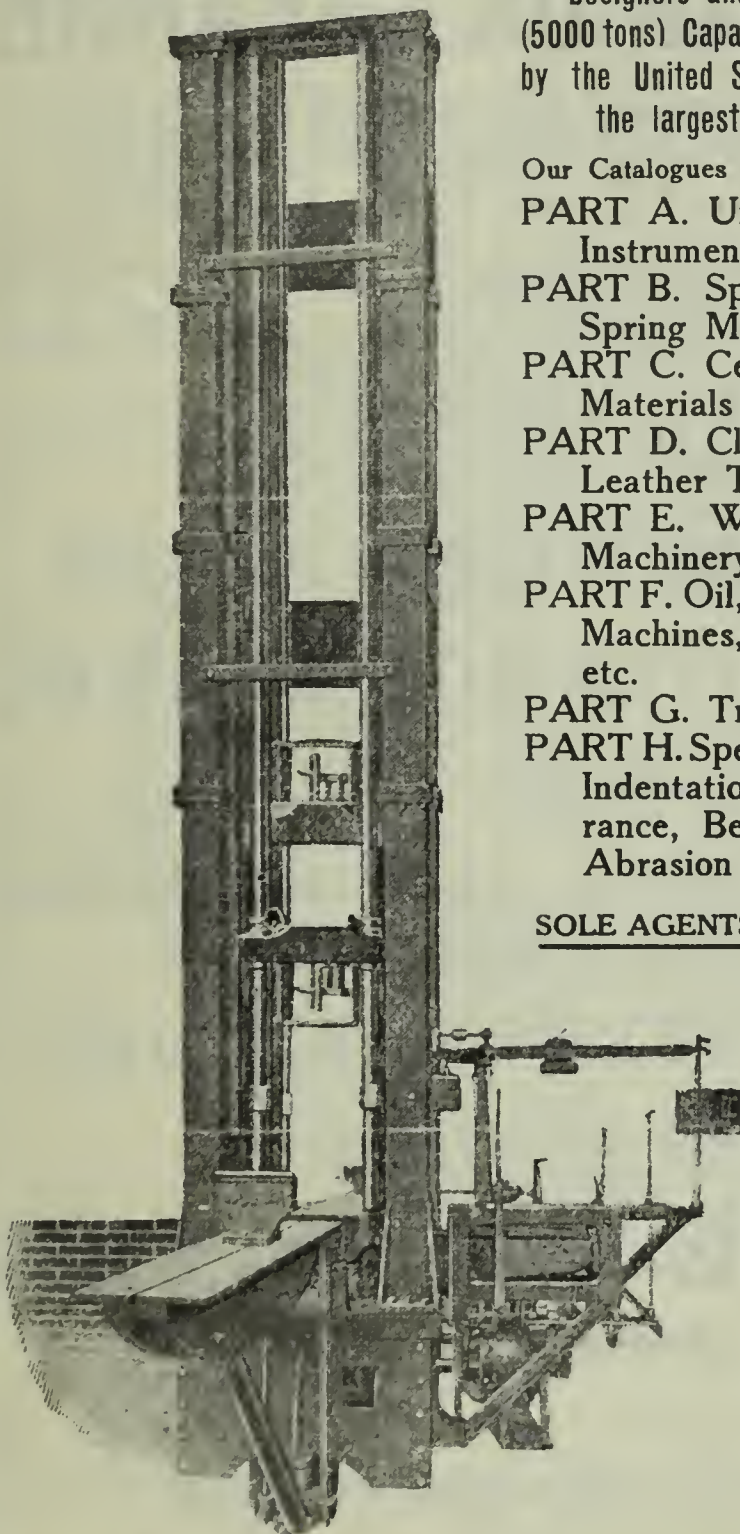
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